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EFFECT OF LATITUDE ON PHENOLOGY OF 'COLT' WINTER WHEAT*

ARMAND BAUER, RICHARD GARCIA, E.T. KANEMASU, B.L. BLAD, J.L. HATFIELD, D.J. MAJOR, R.J. REGINATO and K.G. HUBBARD

Northern Great Plains Research Laboratory, USDA-ARS, Mandan, ND 58554 (U.S.A.)

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ABSTRACT

Bauer, A., Garcia, R., Kanemasu, E.T., Blad, B.L., Hatfield, J.L., Major, D.J., Reginato, R.J. and Hubbard, K.G., 1988. Effect of latitude on phenology of 'Colt' winter wheat. Agric. For. Meteorol., 44: 131-140.

Information is lacking on the effect of latitude, i.e., photoperiod, on winter wheat development rate through heading independent of the effect of temperature. The cultivar 'Colt' was grown in identically-conducted trials at Manhattan, KS and Mandan, ND over a 2-year period which also involved nitrogen rates, water levels, and another cultivar. Plant development stage was monitored at least once a week with designations based on the Haun or Zadoks-Chang-Konzak scale. The flag leaf stage on the main-stem was leaf 7 at Manhattan and leaf 8 at Mandan, regardless of whether autumn-grown leaves froze or did not freeze during the winter. Number of growing degree-days per Haun stage through heading was five to ten lower at Mandan than Manhattan, and differed between years at both locations, but number of photothermal units per Haun stage through heading was greater at Mandan than Manhattan. Conclusive evidence is lacking that photoperiod affected winter wheat development rate independent of air temperature between 39° and 47°N latitude.

INTRODUCTION

Observed differences in plant development rate of winter wheat (*Triticum aestivum* L.) within major growing areas can be reconciled by accounting for differences in air temperature during the growing season. Accumulated growing degree-days (GDD) from planting, emergence, or other point of reference, are at present used extensively in growth and yield models (Baker et al., 1985) to estimate plant development stage.

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In general, the number of GDD required by wheat from planting to heading stage is considered to decrease with increase in latitude (Peterson, 1965), primarily attributed to an increasing number of daylight hours at the higher latitudes. Williams (1971) estimated that (spring) wheat development on the Canadian Great Plains was particularly responsive to photoperiod during emergence to jointing, with the longer photoperiod effecting more rapid plant development. However, after jointing, response to photoperiod decreased because, simultaneously, photoperiod differences diminished and relative temperatures at northern points became progressively cooler. Williams' (1971) daily maximum–minimum temperatures were interpolations from estimates of 1931–1960 normals of mean monthly maximum and minimum temperatures, and photoperiod data were derived with Robertson's equations (1968). Williams also made assumptions of spring planting dates.

The threshold daylength at which photosensitivity is expressed in wheat varies with cultivar within a wheat class. Sensitivity in hard red spring wheats (HRSW) is expressed at photoperiods of 12 hours but not at 14 hours (private communication, Dr. Richard Frohberg, North Dakota State University). Photosensitivity differences among cultivars of hard red winter wheat (HRWW) are only now being widely recognized (private communication, Dr. R.A. Sears, Kansas State University). In Australian wheats, expression of photosensitivity is uncommon with days of 10 or more hours of daylight (Halse and Weir, 1970).

Klepper et al. (1982) in a growth chamber study, showed that each winter wheat leaf requires the same number of days to elongate in any given environment. This time-interval, a phyllochron, can be measured in the field by GDD. The GDD (base $T=0\,^{\circ}C$) per phyllochron range from 80 to 110 with much of the variation resulting from planting date (Klepper et al., 1985). In Oregon, earlier fall planting dates give seedlings which require more GDD per phyllochron. Under semitropical conditions (Wiegand et al., 1981), GDD per phyllochron range from 84 to 198, depending on cultivar and season, with an increase in GDD per leaf for the later-formed leaves. From a controlled environment study, Pirasteh and Welsh (1980) reported that both winter and spring wheat cultivars used more degree-hours to heading at warmer day/night (21/12.7°C) than cooler (15.5/7.2°C) temperatures. This study was conducted under a photoperiod regime that began with light/dark periods of 10/14 hours and increased/decreased one hour every 3 weeks until the thirteenth week. From the thirteenth week to termination, the light/dark period was 14/10 hours.

The precision of the GDD in estimating plant development rate is affected by the definitiveness of the scale used to designate plant development stage. Among the scales used in the Great Plains (Bauer et al., 1983), Haun's (1973) is most definitive because the numerical designations ascribed to each identified morphological unit are further sub-divided into fractions. Similar to the Haun scale in chronologically assigning each main-stem leaf a number as a scale designate, the Zadoks–Chang–Konzak scale (1974) does not employ subdivision designations to describe a developing morphological unit, but it employs multiple designations to describe tillering and stem elongation in detail not associated with the Haun scale.

The photothermal unit (PTU), the product of GDD and daylight hours, was introduced by Nuttonson (1948) as a means of quantifying the combined effect of daylength and thermal energy on plant development rate. At Mandan, ND (Bauer et al.,1984), growing season accumulation of PTU parallels that of GDD, differing by a daily constant factor of about 16.

Assessment of the effect of latitude on winter wheat development rate independent of GDD requires use of at least one cultivar in common in order to eliminate potential confounding because of cultivar differences. Studies reported by Peterson (1965) and by Williams (1971) did not include a cultivar common to all sites. The identically-conducted experiment described by Reginato (1988) provided an opportunity for such an evaluation.

The objectives were (1) to determine if the pre-anthesis development rate of 'Colt' winter wheat at Manhattan, KS and Mandan, ND, differed because of latitude as expressed by accumulation of GDD and PTU, and (2) to determine the effect of nitrogen (N) and water application level on pre-anthesis plant development rate, based on either the Haun or Zadoks–Chang–Konzak scale.

MATERIALS AND METHODS

Descriptions of the sites, experimental design, N and water treatments, and sampling techniques are provided by Reginato et al. (1988). Phenological observations were made at all five North American Great Plains sites at which the study was conducted, but the frequency of observations was insufficient at Lubbock, TX, Lincoln, NE, and Lethbridge, Alberta for use in the evaluation of this aspect of the study.

The cultivar 'Newton' was included with Colt in the experiment at Manhattan, KS (39° 09′N 96° 37′W) and the cultivar 'Norstar' in the experiment at Mandan, ND (46° 46′N 100° 55′W).

Plant development stage, based on either the Haun (1973) or Zadoks et al. (1974) scale, was estimated at least once a week at both locations in both seasons. Development stages based on the Zadoks et al. scale were converted to the Haun scale by standards developed by Bauer et al. (1983). These stages were regressed on linear, quadratic, and cubic functions of the independent variables growing degree-days (GDD) and photothermal units (PTU) accumulated after emergence or other selected time period, using the stepwise forward selection technique provided by SAS (Barr et al., 1976), with 0.05 as the significance level for entry.

Growing degree-days were calculated from daily maximum (T_{max}) and minimum (T_{min}) air temperature measured at 2-m height for each 24 hours, midnight to midnight, as follows

$$\mathrm{GDD}=\left(\frac{T_{max}+T_{min}}{2}\right)-T_b$$

where T_b, base temperature, is 0°C. When daily T_{min} was $<0°$ it was set equal to 0°C for that day.

Photothermal units (Nuttonson, 1948) are the product of degree-days and daylight hours. Daylight is defined as the period between sunrise and sunset, based on computations by the US Naval Observatory (Supt. Documents, 1959).

RESULTS AND DISCUSSION

At Manhattan, plant development rate through heading of the second cultivar Newton was essentially the same as that of Colt both years. But at Mandan in 1986, Colt required fewer GDD through heading than the second cultivar Norstar (Table 1). The development rate of Norstar equalled that of Colt through the flag leaf stage, but apparently the flag leaf extension stage, which follows the flag leaf stage, was abbreviated in Colt relative to Norstar. Thus, Colt completed the heading stage before Norstar.

Neither water nor N level had appreciable effect on development rate through heading (Table 1). Similar results are reported by Klepper et al. (1986). Hence, all data within each location were combined for analysis.

At Manhattan the seventh leaf on the main-stem of Colt and Newton was the flag leaf while at Mandan, the eighth leaf of Colt and Norstar was the flag leaf. This occurred both years. Colt also produced seven leaves on the main stem at Lubbock, TX and Lincoln, NE.

Air temperatures, in the absence of sufficient snow cover during the 1984–1985 winter, were cold enough at both Manhattan and Mandan to effect freezing of autumn-grown plant aerial tissues. Therefore, all development observations of main-stem leaves for the 1985 season are based on those produced after "spring greenup". In contrast, 1985–1986 winter air temperatures were mild enough both at Manhattan and Mandan that, when coupled with a continuous snow cover from late autumn through the winter, the autumn-grown plant aerial tissues did not freeze. Hence, all development observations for the 1986 season are based on tissues produced from emergence. But, regardless of whether tissues froze or not overwinter, the seventh leaf was the flag leaf on the main-stem of the wheats at Manhattan and the eighth on those at Mandan. Thus, during its life cycle, each of these cultivars produced more total leaves on the main-stem in the year that the autumn-grown aerial tissue froze than when it did not.

The accumulated GDD per Haun stage through heading was about five and

TABLE 1

Linear regression of winter wheat plant development (Y) from emergence or spring greenup, Haun scale, and accumulated growing degree-days (X) as affected by cultivar, nitrogen level, and water level

Site	Year	Treatment[a]	n	Regression	R^2
Manhattan	1985	N_1C_1	30	$Y=0.0090X+2.25$	0.97
		N_2C_1	30	$Y=0.0093X+2.17$	0.98
		N_3C_1	30	$Y=0.0095X+1.88$	0.99
		N_4C_1	30	$Y=0.0102X+1.37$	0.99
		W_1C_1	40	$Y=0.0094X+2.00$	0.98
		W_2C_1	40	$Y=0.0092X+2.20$	0.98
		W_3C_1	40	$Y=0.0099X+1.54$	0.98
		N_1C_2	30	$Y=0.0097X+1.59$	0.98
		N_2C_2	30	$Y=0.0093X+2.03$	0.97
		N_3C_2	30	$Y=0.0093X+1.93$	0.98
		N_4C_2	30	$Y=0.0093X+1.77$	0.98
		W_1C_2	40	$Y=0.0093X+1.84$	0.98
		W_2C_2	40	$Y=0.0096X+1.74$	0.97
		W_3C_2	40	$Y=0.0094X+1.91$	0.98
Manhattan	1986	N_1C_1	30	$Y=0.0076X+0.95$	0.98
		N_2C_1	30	$Y=0.0076X+0.95$	0.98
		N_3C_1	30	$Y=0.0073X+1.11$	0.98
		N_4C_1	30	$Y=0.0073X+1.11$	0.98
		W_1C_1	40	$Y=0.0077X+0.89$	0.98
		W_2C_1	40	$Y=0.0073X+1.10$	0.98
		W_3C_1	40	$Y=0.0073X+1.10$	0.98
		N_1C_2	30	$Y=0.0076X+0.95$	0.98
		N_2C_2	30	$Y=0.0076X+0.95$	0.98
		N_3C_2	30	$Y=0.0073X+1.11$	0.98
		N_4C_2	30	$Y=0.0073X+1.11$	0.98
		W_1C_2	40	$Y=0.0077X+0.89$	0.98
		W_2C_2	40	$Y=0.0073X+1.10$	0.98
		W_3C_2	40	$Y=0.0073X+1.10$	0.98
Mandan	1985	N_1C_2	24	$Y=0.0103X+0.68$	0.95
		N_2C_2	24	$Y=0.0100X+0.78$	0.95
		N_3C_2	24	$Y=0.0098X+0.79$	0.94
		N_4C_2	24	$Y=0.0097X+0.81$	0.95
		W_1C_2	32	$Y=0.0100X+0.73$	0.95
		W_2C_2	32	$Y=0.0099X+0.80$	0.94
		W_3C_2	32	$Y=0.0099X+0.76$	0.94

TABLE 1 (continued)

Site	Year	Treatment[a]	n	Regression	R^2
Mandan	1986	N_1C_1	20	$Y=0.0085X+0.59$	0.97
		N_3C_1	20	$Y=0.0084X+0.56$	0.96
		W_1C_1	20	$Y=0.0085X+0.60$	0.96
		W_3C_1	20	$Y=0.0084X+0.54$	0.96
		N_1C_2	20	$Y=0.0076X+1.01$	0.98
		N_3C_2	20	$Y=0.0076X+1.04$	0.97
		W_1C_2	20	$Y=0.0076X+1.04$	0.97
		W_3C_2	20	$Y=0.0075X+1.01$	0.98

[a]N, W, and C refer to nitrogen, water and cultivar.

TABLE 2

Regression of plant development stage (Y) of winter wheat, Haun scale, and accumulated growing degree-days (X) at Manhattan, KS and Mandan, ND, 1984-1985 and 1985-1986

Location	Year	n	Regression	R^2	1/m[a]
Manhattan	84-85	240	$Y=0.00945X+1.9$	0.98	106
Mandan[b]	84-85	96	$Y=0.00995X+0.8$	0.95	101
Manhattan	85-86	240	$Y=0.00742X+1.0$	0.98	135
Mandan	85-86	80	$Y=0.00801X+0.8$	0.96	125

[a]GDD per phyllochron is the reciprocal of the slope. [b]Norstar only.

ten more at Manhattan than Mandan in 1984–1985 and 1985–1986, respectively (Table 2). Fewer GDD were required for each stage in 1984–1985 than 1985–1986 at both locations. The GDD number per Haun stage in these trials is in the range previously reported (Klepper et al., 1985; Wiegand et al., 1981).

Since the autumn-grown aerial tissue froze during the 1984–1985 winter at both locations, the number of GDD per Haun stage was calculated from GDD accumulated after snowmelt was complete, starting with day of year (DOY) 55 at Manhattan and DOY 93 at Mandan. Because one less leaf was produced on the main-stem of Manhattan-grown wheat, the accumulated number of GDD from snowmelt through heading was about 50 less at Manhattan than at Mandan, even though the GDD number per leaf was larger at Manhattan.

Haun plant development stage initially measured after snowmelt in 1985 at Manhattan (DOY 77) and Mandan (DOY 109) was 3.5 and 3.2, respectively. In the interval between snowmelt and the initial staging, GDD accumulation was 173 and 146, respectively, at Manhattan and Mandan. The number of GDD per leaf during this period, 49 and 46, at Manhattan and Mandan respectively, is much less than indicated for each Haun stage through heading. This suggests a curvilinear rather than the linear relationship as shown in Table 2, and also that during early development stages soil rather than air temperature may be a better estimator of winter wheat development rate when autumn-grown tissues freeze. Aerial tissue of winter wheat can develop under

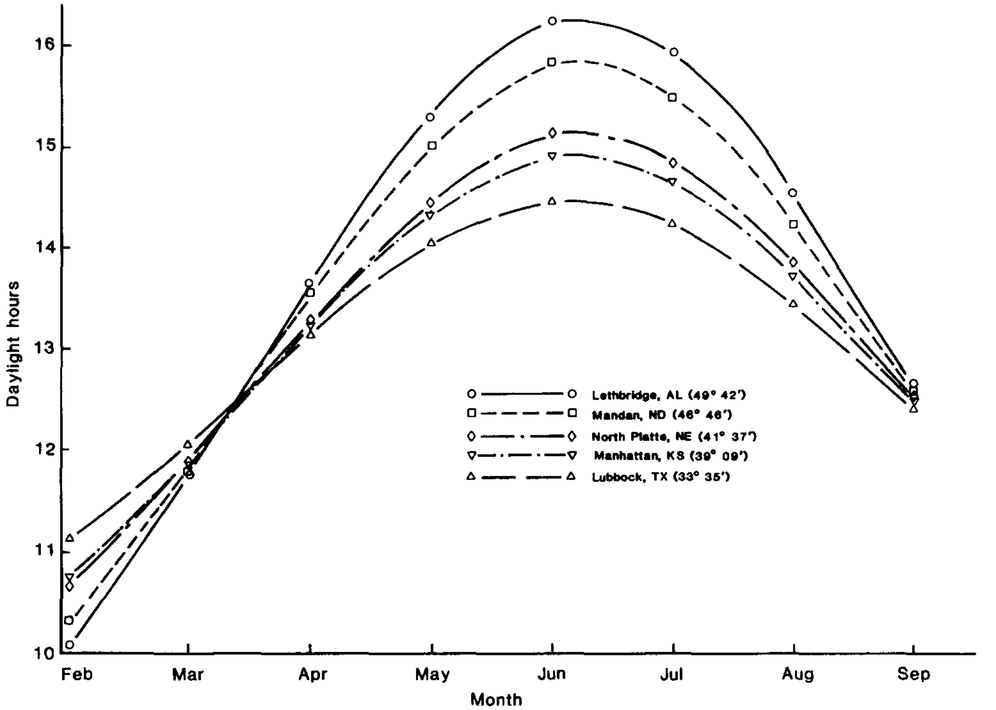

Fig. 1. Hours of daylight, February 15 through September 15, at five locations on the North American Great Plains.

TABLE 3

Regression of plant development stage (Y) of winter wheat, Haun scale, and accumulated photothermal units (X) at Manhattan, KS and Mandan, ND, 1984-1985 and 1985-1986

Location	Year	n	Regression	R^2	1/m[a]
Manhattan	84-85	240	$Y=0.000706X+2.2$	0.98	1416
Mandan[b]	84-85	96	$Y=0.000658X+1.0$	0.95	1520
Manhattan	85-86	240	$Y=0.000564X+1.6$	0.98	1773
Mandan	85-86	80	$Y=0.000524X+1.6$	0.96	1908

[a]PTU per phyllochron is the reciprocal of the slope. [b]Norstar only.

a snow cover, even under snow which has persisted for a prolonged period. (Private communication, Dr. Darryl Smika, UDSA-ARS, Akron, CO.)

In 1985–1986, GDD at both locations were accumulated from emergence in the autumn, since autumn-grown tissues did not freeze during the winter. However, 110 consecutive days (DOY 324 to 67) at Manhattan and 132 consecutive days (DOY 313 to 78) at Mandan, were omitted from the GDD accumulation because of low air temperatures and the presence of snow. Observed Haun stage at Manhattan on DOY 80 was about 4.5 and at Mandan on DOY 91 it was about 3.2.

Favorable air temperatures for plant growth normally occur by late February at Manhattan, about six weeks earlier than at Mandan. Because of the earlier spring growth initiation and the lower latitude at Manhattan, daily hours of daylight under which winter wheat is grown is less at Manhattan than Mandan (Fig. 1). Daylight at Manhattan averages 11.96, 13.24, 14.33, and 14.88 hours in March, April, May, and through June 21, respectively; at Mandan the average is 13.60, 15.03, 15.79, and 15.67 hours in April, May, June, and through July 15, respectively. It would seem that if photoperiod is a factor in plant development rate at these daylengths, photothermal units (PTU) required per Haun stage should be essentially the same at both locations.

In contrast to GDD, the number of PTU per Haun stage was larger at Mandan than Manhattan (Table 3) in both years. But as with GDD, the number of PTU per Haun stage was less in 1984–1985 when autumn-grown aerial tissues froze over the winter than in 1985–1986 when they did not freeze. That the number of PTU per Haun stage was higher at Mandan than Manhattan suggests that the difference in hours of daylight between Manhattan and Mandan had no apparent effect on plant development rate.

SUMMARY

At the flag leaf development stage, the winter wheat cultivars Colt and Newton grown at Manhattan, KS had seven leaves on the main-stem while Colt and Norstar grown at Mandan, ND, had eight leaves on the main-stem.

Water and nitrogen level had little influence on plant development rate through heading stage. Some difference was observed between cultivars at Mandan after the flag leaf stage.

Autumn-grown leaves that froze during the ensuing winter were replaced by new leaves so that leaf 7 and leaf 8 of the main-stem at Manhattan and Mandan, respectively, were the flag leaf. Autumn-grown leaves that were still green in the spring, as in 1985–1986, were part of the total of the seven produced on the main-stem at Manhattan, or the eight at Mandan.

The number of GDD required per Haun development stage through heading was larger at Manhattan than Mandan in both years. The number also differed within each location in the two years. Uncertainty about the starting point for accumulating GDD in the spring appears to be a major contributing factor to differences between years.

The number of PTU required per Haun development stage through heading was larger at Mandan than at Manhattan. The number also differed within each location in the two years. Conclusive evidence is lacking that latitude, hence daylength, affected winter wheat development rate independently of air temperature in these experiments.

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